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(72) Inventor : Havemann, Robert H.

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7413 Stillwater Ct.

Garland, TX 75044 (US)

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(74) Representative : Schwepfinger, Karl-Heinz,
Dipl.-Ing.
Prinz & Partner,
Manzingerweg 7
D-81241 München (DE)

(71) Applicant : TEXAS INSTRUMENTS
INCORPORATED
13500 North Central Expressway
Dallas Texas 75265 (US)

(54) Via formation in polymeric materials.

(57) A semiconductor device and process for making the same are disclosed which use organic-containing materials to reduce capacitance between conductors, while allowing conventional photolithography and metal techniques and materials to be used in fabrication. In one structure, patterned conductors 18 are provided on an interlayer dielectric 10, with an inorganic substrate encapsulation layer 32 deposited conformally over this structure. A layer of an organic-containing dielectric material 22 (pure parylene, for example) is then deposited to substantially fill the gaps between and also cover the conductors. An inorganic cap layer 24 of a material such as SiO₂ is deposited, followed by a photolithography step to define via locations. Vias are etched through the cap layer, and then through the organic-containing dielectric (this step may also be used to strip the photoresist). An inorganic via passivating layer 30 is conformally deposited and then anisotropically etched to clear the bottom of the vias while leaving a passivating liner in the via, preventing the via metal from contacting organic-containing material. A second application of these steps forms a second, overlying structure of patterned conductors 38, inorganic encapsulating layer 36, organic-containing dielectric layer 40, and inorganic cap layer 42.

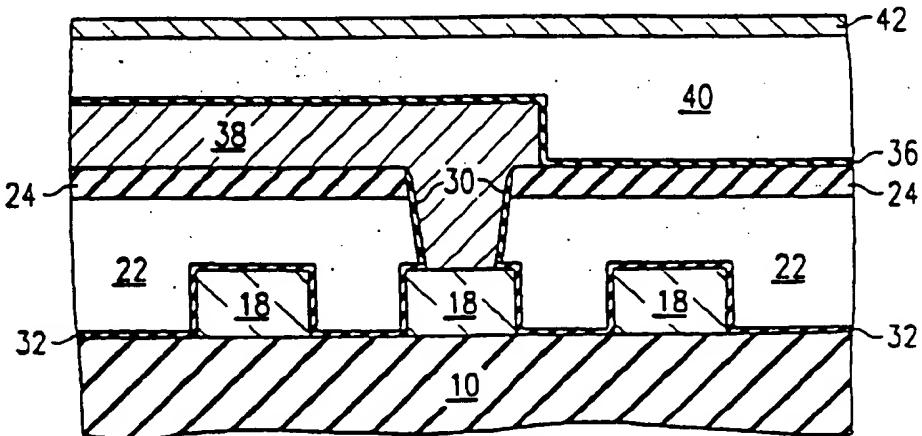


FIG. 4

FIELD OF THE INVENTION

This invention relates generally to the fabrication of semiconductor devices, and more particularly to methods and structures for using organic-containing materials as intra/interlevel dielectrics.

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BACKGROUND OF THE INVENTION

Semiconductors are widely used in integrated circuits for electronic devices such as computers and televisions. These integrated circuits typically combine many transistors on a single crystal silicon chip to perform complex functions and store data. The need to integrate more functions and more storage capacity onto a chip has caused the semiconductor industry to search for ways to shrink, or scale, the size of individual transistors and other devices commonly integrated on a chip. However, scaling devices to smaller dimensions can create a multitude of undesirable effects. One of these effects is an increase in the capacitive coupling between conductors in a circuit, since the capacitive coupling is inversely proportional to the distance between the conductors. This coupling may limit the ultimate speed of the device or otherwise inhibit proper device operation, if steps are not taken to reduce the coupling.

The capacitance between conductors is also highly dependent on the insulator, or dielectric, used to separate them. Conventional semiconductor fabrication commonly employs silicon dioxide as a dielectric, which has a dielectric constant of about 3.9. Many alternate materials have been used or suggested as a way of providing a lower dielectric constant. One such group of materials is organic polymer-containing dielectrics.

SUMMARY OF THE INVENTION

Organic-containing dielectric materials possess many desirable qualities, but it is herein recognized that they are plagued by problems which make their use difficult. One of the problems related to the use of organic-containing dielectrics is that they are generally removed by the same etching procedures commonly used to remove photoresist (a temporary material which is deposited on semiconductor devices to create patterns for various device layers). Other problems with organic-containing materials are the difficulty in adhering contact metal to them, and the possibility of organic-containing materials out-gassing during deposition of adjoining contact metal and reacting with the metal.

The present invention provides a method and structure for creating organic-containing dielectric layers which contain vias on a semiconductor device, allowing electrical connections between conductors above and below the dielectric layer. The present invention uses a novel combination of processing steps to create lined vias through organic-containing dielectrics, thereby both enhancing compatibility with metal processing and preventing damage to the organic-containing dielectrics by subsequent photolithography steps. The organic-containing dielectrics are also desirable because of their relatively low dielectric constant, compared to silicon dioxide dielectrics.

The present invention provides a method for fabricating dielectrics for semiconductor devices with reduced dielectric constant, compared to conventional oxide fabrication techniques, while maintaining compatibility with common semiconductor metal deposition and photolithography materials and techniques. The method can comprise forming a layer of patterned conductors on a substrate, where the substrate may be an actual semiconductor substrate or a previous interlayer dielectric, covering the patterned conductors and substrate with a layer of organic-containing material, and depositing an inorganic cap layer of a material such as SiO₂ over the organic-containing layer. The method can further comprise etching of vias through the cap layer and the organic-containing layer, depositing an inorganic conformal passivating layer over all exposed surfaces, and removing the passivating layer from horizontal surfaces, including the top surface of the cap layer and the bottoms of the vias. This creates a passivating liner which can provide physical isolation for the organic-containing dielectric during subsequent metal deposition or photoresist strip processing steps. One possible variation of the method can provide a total encapsulation of the organic-containing material by an inorganic material such as oxide, preventing contact between the organic-containing dielectric and the underlying conductors also.

Preferably, the organic-containing material is an organic polymer, such as parylene or a polyimide. The organic-containing material may also be a polymer-containing oxide which can be applied as an SOG (spin-on glass), such as the Allied Signal 500 series. The cap layer and passivating layer(s) are preferably composed of inorganic materials such as silicon nitride or compounds containing at least 95% silicon dioxide by weight.

A semiconductor device according to the present invention can comprise a layer of patterned conductors formed on a substrate, where the substrate can be an actual semiconductor substrate or a previously deposited interlayer dielectric, with an organic-containing dielectric layer substantially filling the spaces between and covering the conductors to a depth at least 50% of their height. The device can further comprise a cap layer

composed of inorganic material deposited over the organic-containing layer, and at least one via etched through the cap layer and organic-containing layer for the purpose of allowing contacts to be made to the conductors. The device can further comprise a passivating layer deposited on the exposed portions of the organic-containing layer in the vias, and conducting material deposited in the vias so as to provide electrical connections to the patterned conductors.

BRIEF DESCRIPTION OF THE DRAWINGS

This invention, including the features and advantages thereof, can be best understood by reference to the following drawings, wherein:

FIGS. 1A-1E are cross-sectional views showing the progressive steps in the fabrication of a layer of patterned conductors, an organic-containing dielectric layer with an overlying cap layer, a via through the cap layer and organic-containing dielectric layer, and the creation of via sidewalls;

FIGS. 2A-2C are cross-sectional views of a second embodiment containing a metal/substrate encapsulation layer over the patterned conductors and employing a portion of the cap layer as a sacrificial layer to clear the bottom of the via;

FIGS. 3A-3C are cross-sectional views of another embodiment containing a similar encapsulation layer, but employing a double hard mask technique to clear the bottom of the via; and

FIG 4 is a cross-sectional view of a two-level embodiment, wherein a filled via is shown electrically connecting conductors on two conductor layers, with both layers constructed using an organic-containing dielectric with an inorganic cap layer.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In one embodiment, this invention provides a method for fabricating organic-containing dielectric layers with a capping passivation layer and passivation liners in vias passing through the organic-containing dielectric layer. The method of this embodiment is illustrated in Figure 1. With reference to Figure 1A, a conducting layer 12 is deposited on an insulating layer 10. Conducting layer 12 may be connected through insulating layer 10 to an underlying structure (not shown). A layer of photoresist 14 is spun on over conducting layer 12, exposed through a mask pattern and developed, such that the photoresist layer 14 contains gaps 16 where conducting layer 12 is to be removed. Referring now to Figure 1B, conducting material has been removed using an etching process which removes material below gaps in the photoresist layer to create patterned conductors 18 separated by gaps 20. The photoresist 14 of Figure 1A has also been stripped and does not appear in Figure 1B. Figure 1C shows additional layers added to the structure. An organic-containing dielectric layer 22 fills the gaps 20 of Figure 1B, as well as covering patterned conductors 18 to a thickness roughly equivalent to the thickness of the conductors themselves (layer 22 generally having a depth measured in gap 20 of at least 150% of conductor thickness and shown as 200% of conductor thickness). This organic-containing layer may, for example, be made out of an organic polymer such as parylene, which may be deposited using a vapor-phase polymerization method. An inorganic cap layer 24, made of silicon dioxide for instance, is deposited over the organic-containing dielectric layer 22 (this layer may optionally be planarized, e.g. using a chemical-mechanical polisher), and a new layer of photoresist 26 is then deposited over the inorganic cap layer 24. A via 28 is shown after mask patterning and developing of photoresist layer 26, and after anisotropic etch of inorganic cap layer 24. An anisotropic etch of via 28 through dielectric layer 22 may also serve to strip photoresist 26 from the device, if both are affected by the same etching procedure. Figure 1D illustrates the device after via 28 has been etched through dielectric layer 22 to conductor 18. This figure also shows an inorganic via passivation layer 30 applied conformally over the exposed surfaces of the device. Preferably, via passivation layer 30 is constructed of a material similar to inorganic layer 24, although this is not required. Finally, Figure 1E shows the via passivation layer 30 remaining only on the via sidewalls, after an anisotropic etch has been used to remove passivation material from the bottom of the via and from the top of the hard mask. This configuration is desirable because it provides decreased capacitive coupling, while maintaining inorganic surface materials such as oxides and nitrides for subsequent via metallization, photolithography, and other steps.

Figures 2A-2C show a second embodiment which includes an inorganic substrate encapsulation layer 32 deposited conformally over the patterned conductors 18 and substrate 10. Figure 2A shows the structure after patterning of the conductors and deposition of encapsulation layer 32. Steps similar to those of the first embodiment are then performed to construct the cross-section of Figure 2B. This embodiment differs in that the bottom of via 28 is now obstructed by both substrate encapsulation layer 32 and via passivation layer 30. Clearing the bottom of the via utilizes an anisotropic etch which can remove both obstructing layers. Since only via passivation layer 30 exists on top of cap layer 24, the cap layer may be deposited with additional thickness

designed to be sacrificial; that is, a portion of the cap layer may be removed during etching of the passivating layers. An additional advantage afforded by this embodiment is that organic-containing layer 22 may be completely enclosed by the passivating and encapsulating material, such that conducting material is completely isolated from organic-containing material.

5 Another method which may be used with a substrate encapsulation layer is depicted in Figures 3A-3C. Figure 3A is identical to Figure 2A, but Figure 3B shows a cap layer 24 covered by a hard mask layer 34 which is formed of an inorganic material resistant to the passivation/encapsulation layer etch. One choice may be a silicon nitride hard mask, if for example, passivating layer 30 and encapsulation layer 32 are constructed of primarily silicon dioxide. This embodiment may require an additional etch step during via opening to remove
10 hard mask layer 34 from the via opening. After via etching of hard mask layer 34, cap layer 24, and dielectric layer 22, via passivation layer 30 is formed to directly overlay hard mask layer 34 instead of cap layer 24. The anisotropic etch to dear the bottom of via 28 now will remove passivation layer 30 from at least the top surfaces of hard mask layer 34. The hard mask layer then acts as an etch stop to prevent etching into cap layer 24, although the tops of the passivation layer 30 lining the via sidewalls are not protected from the etch. After the
15 bottom of via 28 is cleared, hard mask 34 may be left in place. As an alternative, the hard mask may be removed by a selective etch to complete the structure of Figure 3C.

Figure 4 shows a cross-section of an embodiment of the invention which illustrates how the various features and advantages of the invention may be employed on multiple layers of patterned conductors. An intermediate structure similar to that of Figure 2C is built upon by first adding a second layer of patterned conductors 38 above cap layer 24 and in via 28. This layer may be formed by depositing several sublayers (Ti/TiN/AlCu alloy, for example) of conducting material over the structure and patterning this material in a manner similar to the formation of conductors 18. After patterning of the second conducting layer, a second substrate encapsulation layer 36 is deposited over the exposed surfaces of cap layer 24 and second conductor layer 38, followed by a second organic-containing dielectric layer 40 and a second cap layer 42. If connections to yet another overlying layer of conductors (not shown) is desired, via formation on the second conducting layer may then proceed according to one of the methods of the invention.

The table provides an overview of some embodiments and the drawings.

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Table

Drawing Element	Preferred or Specific Examples	Generic Term	Other Alternate Examples
5 10	SiO_2	Substrate	Other oxides, P-glass, silicon nitride, tetraethylorthosilicate (TEOS), cap layer from previous application of invention
10 12,18,38	AlCu alloy with Ti or TiN underlayers	Patterned conductors	Al, Cu, Mo, W, Ti, and alloys of these Polysilicon, silicides, nitrides, carbides
15 14, 26		Photoresist	
20 22,40	Parylene	Organic-containing dielectric layer	Polymeric SOG such as Allied Signal 500 series, amorphous Teflon, polyimides, other organic polymers
25 24,42	Silicon dioxide	Inorganic cap layer	Other oxides, doped SiO_2 , P-glass Silicon nitride
30 30	Silicon dioxide	Inorganic via passivation layer	Other oxides, doped SiO_2 , P-glass Silicon nitride
30 32,36	Silicon dioxide	Inorganic substrate encapsulation layer	Other oxides, doped SiO_2 , P-glass Silicon nitride
35 34	Silicon nitride	Hard mask layer	oxynitrides, <u>other</u> materials resistant to passivation layer etchants

40 The invention is not to be construed as limited to the particular examples described herein, as these are to be regarded as illustrative, rather than restrictive. The invention is intended to cover all processes and structures which do not depart from the spirit and scope of the invention. For example, it would be immediately obvious to one skilled in the art that the relative thicknesses of illustrated layers may be changed to enhance stated or other advantages of the present invention. Also, properties of some of the specific examples may be combined without deviating from the nature of the invention

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Claims

50 1. A method for fabricating electrical connections on semiconductor devices, said method comprising:
 providing a layer of patterned conductors, formed on a substrate;
 filling spaces between and covering said conductors with an organic-containing dielectric layer;
 depositing a cap layer composed of inorganic material over said organic-containing dielectric layer;
 etching one or more vias through said cap layer and said organic-containing dielectric layer;
 depositing a passivation layer on said cap layer and on exposed surfaces within said vias, said exposed surfaces including the bottoms of said vias; and
 55 removing said passivation layer from bottoms of said vias, whereby a lined via is provided for completing electrical connections to said conductors with said lined via and said cap layer separating said

organic-containing dielectric from said electrical connections.

2. The method of claim 1, further comprising providing said passivation layer as an inorganic conformal via passivation layer providing said organic-containing dielectric layer having a dielectric constant of less than 3.5, and composed of a material containing 10% to 100% organic by weight; and whereby a reliable connection can be made through said organic-containing dielectric, and whereby said organic-containing dielectric reduces the capacitance between said conductors as compared to a silicon dioxide dielectric.

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3. The method of claim 1 or claim 2, further comprising selecting said patterned conductors from the group consisting of: aluminum, copper, titanium, platinum, gold, tungsten, polysilicon, TiN, tantalum, TiSi₂, and combinations thereof.

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4. The method of any preceding claim, wherein said step of depositing an organic-containing material comprises spinning on an organic-containing SOG and annealing at a temperature greater than 300 degrees C.

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5. The method of any preceding claim, wherein said step of depositing an organic-containing material comprises depositing a pure polymer by vapor deposition or sputtering.

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6. The method of any preceding claim, further comprising forming said cap layer and said passivation layer composed of more than 95 weight % silicon dioxide, silicon nitride, or combinations thereof.

7. The method of any preceding claim, wherein said removing step comprising anisotropically removing the passivation layer and portions of said passivation layer on said cap layer and removes a top portion of said cap layer, while leaving said cap layer intact.

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8. The method of any preceding claim, further comprising:
depositing an inorganic substrate encapsulation layer conformally over exposed portions of said patterned conductors and said substrate, before said filling and covering steps; and
removing said substrate encapsulation layer from bottoms of vias, as part of or after said removing of said via passivating layer step.

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9. The method of claim 8, further comprising providing said cap layer comprising at least two sublayers, with a top sublayer formed of a material substantially unaffected by the etch of said via passivation layer.

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10. The method of claim 9, further comprising removing said top sublayer after said removal of said passivation layers.

11. A semiconductor device which comprises:
a layer of patterned conductors formed on a substrate;
an organic-containing dielectric layer filling spaces between and covering said conductors;
a cap layer comprised of inorganic material deposited over said organic-containing layer;
at least one via etched through said cap layer and said organic-containing layer;
an inorganic passivating layer deposited on the sidewalls of said via where said via passes through said organic-containing dielectric; and
an electrical connection formed by filling said via with a conducting material, said electrical connection being connected to one of said patterned conductors, whereby connection can be made to a second level of patterned conductors deposited above the inorganic dielectric layer.

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12. The device of claim 1, wherein the organic containing layer has a dielectric constant of less than 3.5, said organic-containing layer composed of a material containing 10% to 100% polymer by weight

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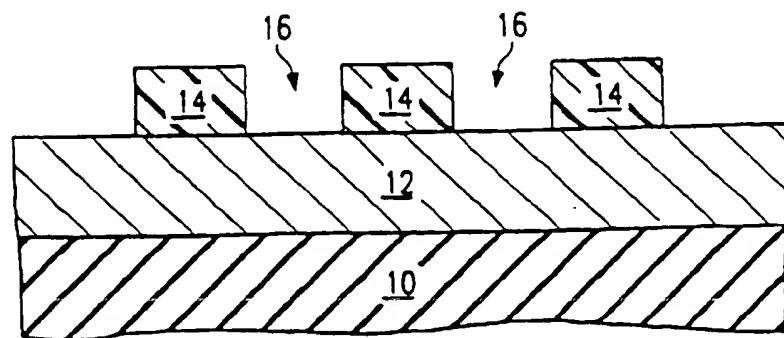


FIG. 1A

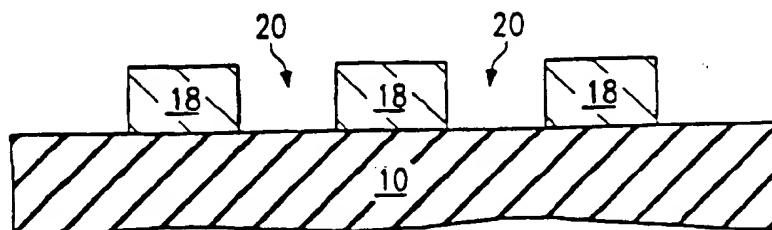


FIG. 1B

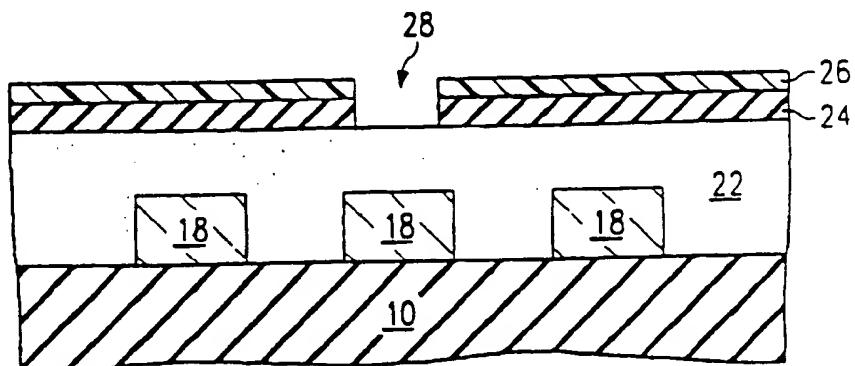


FIG. 1C

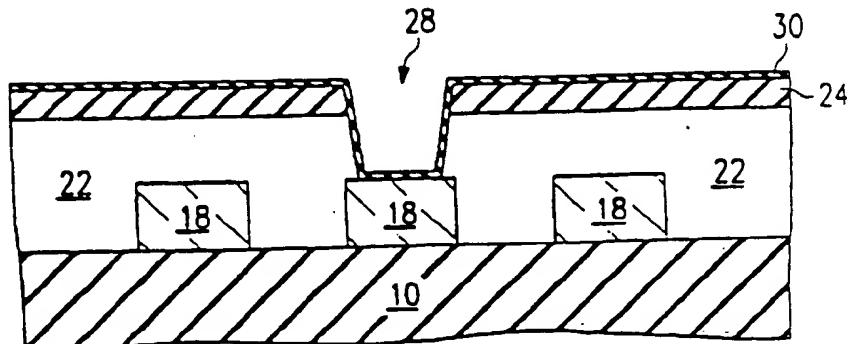


FIG. 1D

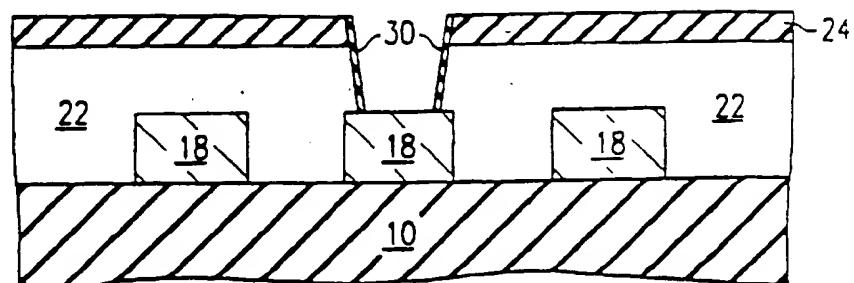


FIG. 1E

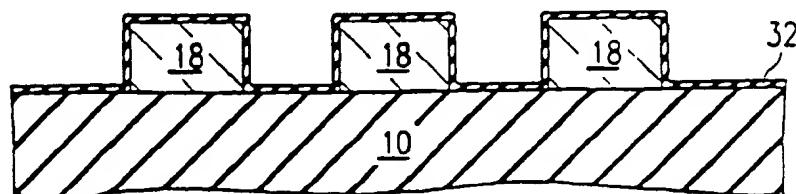


FIG. 2A

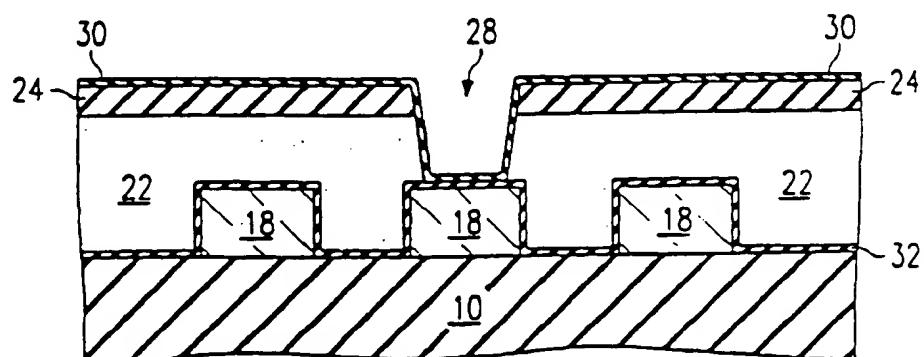


FIG. 2B

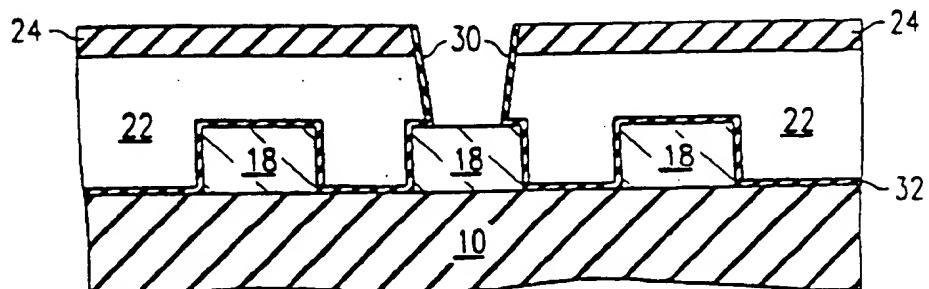


FIG. 2C

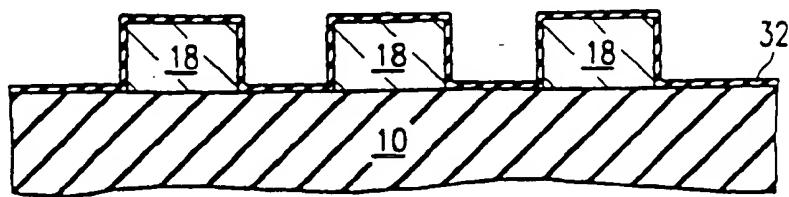


FIG. 3A

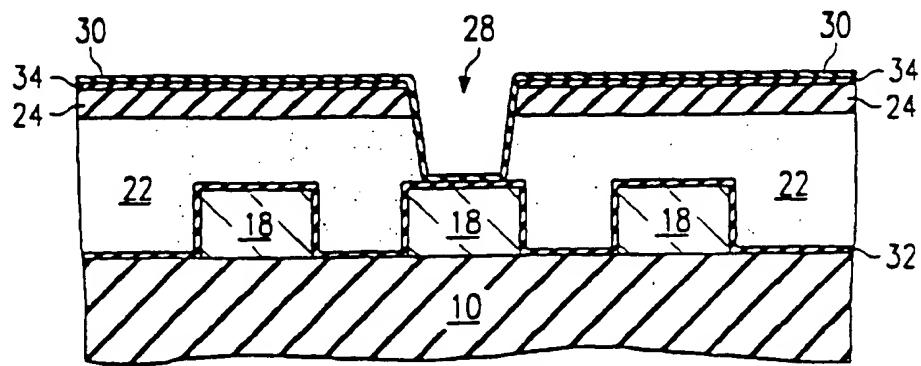


FIG. 3B

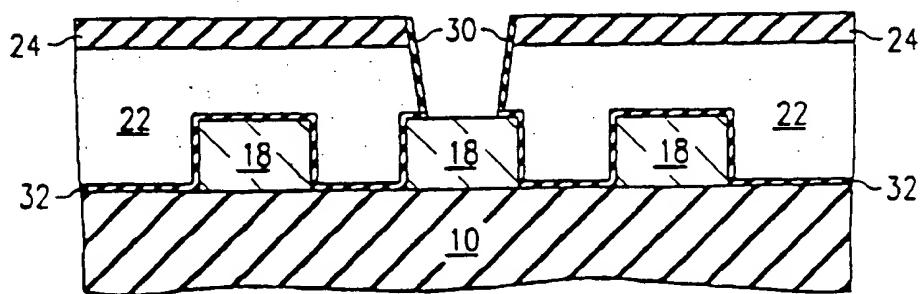


FIG. 3C

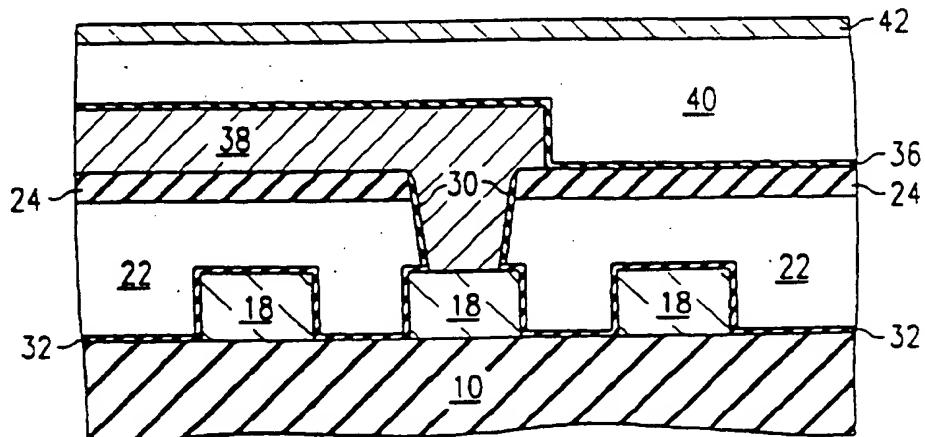


FIG. 4



European Patent
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EUROPEAN SEARCH REPORT

Application Number
EP 95 10 6399

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claims	CLASSIFICATION OF THE APPLICATION (Int.Cl.)
X	EP-A-0 177 845 (SIEMENS AG) 16 April 1986 * column 2, line 32 - line 35 * * column 3, line 4 - line 47 * ---	1,3,6, 11,12	H01L21/768
A	PATENT ABSTRACTS OF JAPAN vol. 018 no. 359 (E-1574) ,6 July 1994 & JP-A-06 097299 (NEC YAMAGATA LTD) 8 April 1994, * abstract * ---	7	
A	US-A-5 284 801 (PAGE ALLEN ET AL) 8 February 1994 * column 2, line 47 - column 3, line 20 * * column 4, line 41 - column 7, line 46 * * figures 1-9 * ---	8	
A	EP-A-0 474 383 (MOTOROLA INC) 11 March 1992 * page 1, line 10 - line 30 * * page 1, line 54 - page 2, line 45 * ---	2,4	
A	THIN SOLID FILMS, 25 SEPT. 1993, SWITZERLAND, vol. 232, no. 2, ISSN 0040-6090, pages 256-260, KUBONO A ET AL 'Direct formation of polyimide thin films by vapor deposition polymerization' * abstract * -----	5	TECHNICAL FIELDS SEARCHED (Int.Cl.) H01L
<p>The present search report has been drawn up for all claims</p>			
Place of search	Date of compilation of the search	Examiner	
THE HAGUE	4 August 1995	Schuermans, N	
CATEGORY OF CITED DOCUMENTS		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : see-written disclosure P : intermediate document			